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Strategies and actions to overcome Industrial Symbiosis barriers. Mapping and findings from the Italian working field

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Author: **Matteo Pavesi**

Student ID: 970749
Advisor: Prof. Davide Chiaroni
Co-advisors: Alessio Nasca, Lucrezia Sgambaro
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Abstract

This thesis will describe one of the operational practices of the Circular Economy, Industrial Symbiosis. Starting from an introduction pointing out actions and trends influencing the world economic context, it continues with a macro section dedicated to Legislation, policies and activities proposed by European Commission and the italian Parliament.

A review of the academic literature has been performed to grasp better the magnitude that Industrial Symbiosis could have on the production landscape. The goal was to propose a set of possible definitions and conclude by suggesting a working one capable of encompassing the evolution path of the Sustainability research field. Furthermore, a taxonomy is proposed and adopted that identifies the different industrial symbiosis types to contextualise Italian mapping. Finally, is presented the first, and still one of the best cases, the Kalundborg one.

The core of this deliverable is presented in the third chapter, where Italian mapping and interviews are presented. A few notable examples from the Italian playground are described. The facilitator's role has a dedicated section highlighting how it can play a pivotal role in fostering Industrial Symbiosis. All the interviews conducted are proposed underlying the barriers that entrepreneurs and managers face in applying the concept.

This deliverable concludes with a barrier and enabler study comparing theoretical and working ones. The chapter concludes with a critical analysis of the latter results and what actions can be implemented to facilitate this good practice.

Industrial Symbiosis, Circular Economy, Legislation, Policies, Italian mapping, Interviews, Facilitators

Abstract

Questa tesi descriverà una delle pratiche operative dell'economia circolare, la simbiosi industriale. Partendo da un'introduzione che evidenzia azioni e tendenze che influenzano il contesto economico mondiale, si prosegue con una macrosezione dedicata alla Legislazione e alle attività politiche proposte dalla Commissione Europea e dal Parlamento Italiano.

Una revisione della letteratura accademica è presente nell'elaborato al fine di cogliere l'impatto che la Simbiosi Industriale possa avere sul panorama produttivo. L'obiettivo era quello di proporre un set di possibili definizioni e concludere formalizzandone una che sia in grado di racchiudere l'evoluzione che la Sostenibilità, come filone di ricerca, ha avuto negli ultimi anni. Inoltre, viene proposta e adottata una tassonomia che identifica i diversi tipi di simbiosi industriale per meglio contestualizzare la mappatura italiana. Per concludere, in questa sezione viene presentato il primo, e tuttora uno dei migliori casi, quello di Kalundborg.

Il nucleo di questo elaborato è presentato nel terzo capitolo, dove vengono presentate la mappatura italiana dei casi di Simbiosi Industriale e le interviste condotte. Vengono descritti alcuni esempi di rilievo. Viene presentata e descritta la figura del facilitatore, ruolo fondamentale nella promozione della Simbiosi Industriale. Tutte le interviste condotte durante il periodo di tesi vengono analizzate sottolineando le barriere che imprenditori e manager han dovuto affrontare nel rendere reale il proprio caso di Simbiosi Industriale.

Grazie alla mappatura e agli approfondimenti fatti nelle interviste si conclude con uno studio sulle barriere e sui fattori abilitanti. Viene inoltre fatto un confronto tra ciò che risulta dagli articoli e dall'interviste, nello specifico quali barriere trovano conferma dai casi reali. La sezione si conclude con un'analisi critica di quest'ultimi risultati e infine, quali azioni possono essere messe in atto per agevolare questa buona pratica.

Simbiosi Industriale, Economia Circolare, Leggi e Iniziative, Mappatura dello stato dell'arte, Facilitatori

Contents

1 | Introduction

Sustainable Development Goals Agenda 2030 [3], rectified by United Nations, and the Paris Climate [2], signed in 2016 by 195 members, are the two well-known initiatives fostering the transition towards a productive model in which profitability is no longer the only and unique object to be achieved. Those initiatives are well supported and pushed by legislations and policies, which are deeply analysed in chapter 2. Furthermore, economic and social trends say that population and consumption are growing. People are moving towards mega-cities, and their needs are changing. Market requests are shaping new product designs, which must be innovative and connected. Those drifts imply further materials usage, such as bios composites and rare earth elements, to build new products and green technologies (e.g., photovoltaic panels or wind turbines).

In 2018 the Italian production of special waste amounted to approximately 143.5 Mton, with an increase of 3.3% compared to 2017. In quantitative terms, the growth is almost entirely attributable to non-hazardous waste, particularly those from construction and demolition operations which increased by 6.6%, equal to 3.7 million tons [5]. The last published date comes from 2020, with a display of 147 Mton of special waste, with a reduction of 4.5% compared to 2019 [48]. As for municipal waste, data on waste generated by production activities (industrial, commercial, craft, service, waste treatment and environmental remediation) were strongly affected by the emergency health from Covid-19, which marked, in 2020, the national socio-economic context.

In this context, especially nowadays, a crucial aspect must be highlighted: the scarcity of natural resources. Raw material global supply chains are under pressure from the recent Ukrainian-Russian war and relative sanctions. Demand and competition for finite and sometimes scarce resources will continue to increase, and pressure on resources is causing more significant environmental degradation and fragility.

Europe can benefit economically and environmentally from making better use of those resources. Indeed, a new sustainable model in which people, profit, and planet (3P [21, 22]) spheres are pursued simultaneously is desirable. Moving towards a more circular economy is essential to deliver the resource efficiency agenda established under The European

Green Deal [47]. Nevertheless, even in a highly circular economy, some element of linearity will remain as virgin resources are required, and residual waste is disposed of. The industry already recognises a strong business case for improving resource productivity. It is estimated that resource efficiency improvements all along the value chains could reduce material inputs needs by 17% - 24% by 2030 [39], and better use of resources could represent an overall savings potential of 630 billion euro per year for European industry [12]. Turning waste into a resource is part of closing the loop in circular economy systems. The European Union has set out its political commitment to reduce waste generation, recycle waste into a significant, reliable source of raw materials for the Union, recover energy only from non-recyclable materials, and virtually eliminate landfilling. Two sides influence this playground. The former, upstream, suggests increasing the efficiency of the production processes by reducing raw material usage, avoiding quality detriment, or reducing waste. The latter, downstream, means keeping the residual value within the circle. Those two aspects are the essence of the Circular Economy, which aims to foster technological innovation, propose innovative business models and spread sustainable knowledge. In this specific circular economy context, Industrial Symbiosis is one of the possible operations by which wastes or by-products of an industry or industrial process become the raw materials for another. Application of this concept allows materials to be used more sustainably and contributes to creating a circular economy.

2 | Legislations, Policies and Actions

One of the first steps of the new European Commission led by Ursula von der Leyen was to adopt, in December 2019, the Green Deal, a roadmap to make the EU a world leader in circular economy and clean technologies. In this direction, the Circular Economy Action Plan of 2015 was updated at the beginning of March 2020. Immediately after its presentation, the health emergency linked to the coronavirus began. In addition to the sick and dead, it is rapidly becoming a severe economic crisis with the impoverishment of millions of people and a substantial increase in social hardship.

It is essential to underline that the transition towards a circular economy needs the adoption of specific pathways in every Member State, region and city based on geographical, environmental, economic, legislative and social factors. Thus, regions and cities certainly have a crucial role in implementing a multi-level governance model which can start and accelerate the transition of the Italian system. For this reason, it is vital that regions within a national strategy on the circular economy, having consulted all stakeholders, elaborate their strategical documentation and plans containing, for example, local priorities, planned measures and available resources. This would give local, regional, and national stakeholders a clear indication of planning activities in the long term.

The valorisation of residues as by-products in Industrial Symbiosis paths allows win-win solutions in which all actors can benefit from reciprocal interactions. Policies and Legislation play a pivotal role in fostering those kinds of collaborations. This chapter proposed a European and Italian legislation review, focusing strictly on those that can influence IS cases of adoption.

2.1. Europe

2.1.1. Circular Economy action plan

The EU's Circular Economy Action Plan [13] (CEAP) was a vast body of legislative and non-legislative actions adopted in 2015, which aimed to transition the European economy from a linear to a circular model. The Action Plan mapped out 54 activities and four legislative proposals on waste. These legislative proposals were put forward by the European Commission along with the Action Plan and included targets for landfill, reuse, and recycling, to be met by 2030 and 2035, along with new obligations for separate collection of textile and biowaste. The Action Plan covered several policy areas, material flows, and sectors alongside cross-cutting measures to support this systemic change through innovation and investments. It also announced a sectoral strategy for plastics. More than 10 billion in public funding was allocated to the transition between 2016 and 2020. All 54 actions were adopted or implemented by 2019. The EU is now recognised as a leader in circular economy policymaking. The waste legislation was adopted in 2018, following negotiations with the European Parliament and the Member States. According to Eurostat, jobs related to circular economy activities have increased by 6% between 2012 and 2016 within the EU. The action plan has also encouraged 14 Member States, eight regions, and 11 cities to implement circular economy strategies.

2.1.2. European Green deal

The European Green Deal [28] presents a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all. The European Green Deal aims to boost the efficient use of resources by moving to a clean, circular economy, stopping climate change, reverting biodiversity loss and reducing pollution. It outlines investments needed and financing tools available and explains how to ensure a just and inclusive transition.

The European Green Deal covers all sectors of the economy, notably transport, energy, agriculture, buildings, and industries such as steel, cement, ICT, textiles and chemicals. It embraces various policy areas. Moreover, it provides an action plan to boost the efficient use of resources by moving to a clean, circular economy, restoring biodiversity, and reducing pollution.

Figure 2.1: The European Green Deal actions plan. [source: `https://euinasean.eu/eu-green-deal/`]

Actions involved in the EU Green Deal influencing Industrial Symbiosis:

- The Circular Economy Package has been adopted to boost global competitiveness, foster sustainable economic growth and generate new jobs. It consists of two EU Action Plans for the Circular Economy (2015 and 2020), with measures covering the entire life cycle of products: from production and consumption to waste management and the market for secondary raw materials. The CEAP II focuses on resource-intensive sectors with a high potential for circularity, aiming to keep resources in economic cycles as long as possible. The plan addresses critical product value chains: electronics and ICT, batteries and vehicles, packaging, plastics, textiles and food.

- The proposal for a Regulation on Ecodesign for Sustainable Products addresses product design, which determines up to 80% of a product's lifecycle environmental impact. It sets new requirements to make products more durable, reliable, reusable, upgradable, reparable, easier to maintain, refurbish and recycle, and energy and resource-efficient. In addition, product-specific information requirements will ensure consumers know the environmental impacts of their purchases. All regulated products will have Digital Product Passports, making repairing or recycling products easier and facilitating tracking of substances of concern along the supply chain. The new proposal extends the Ecodesign framework in two ways: first, to cover the broadest possible range of products, and second, to broaden the scope of the requirements with which products are to comply.

- The new 2030 Biodiversity Strategy is a comprehensive, systemic and ambitious long-term plan for protecting nature and reversing the degradation of ecosystems. It is a key pillar of the European Green Deal and EU leadership on international action for global public goods and sustainable development goals. To put Europe's biodiversity to recovery by 2030, the Strategy sets out new ways to implement Legislation more effectively, new commitments, measures, targets and governance mechanisms.
- The Zero Pollution Action Plan provides a compass to mainstream pollution prevention in all relevant EU policies, step up implementation of the applicable EU legislation, and identify possible gaps. It includes targets on air, water, soil, noise pollution, waste generation and biodiversity

2.1.3. Directive 2018/851/EU

The recent Directive, 2018/851/EU [16], amended Article 5 (on by-products) of Directive 2008/98/EC [15] , requiring Member States to take "appropriate measures" to ensure that a substance or object, resulting from a process of production whose purpose is not the production of that substance or thing, is not considered a waste but a by-product. According to the provisions of Article 5, measures can be established at the national level through the adoption of detailed criteria on the above conditions for specific substances or objects (where standards have not been set at the Union level), favouring replicable practices of industrial symbiosis. The European Union, therefore, urges Member States to give new impetus to the by-product sector and industrial symbiosis to do this practice, in compliance with sector regulations, a practical system reality.

2.2. EU Legislation remark

The EU Commission will play a pivotal role in promoting all political reforms. It will cooperate with Member States, regions, and cities in making the best use of EU funds. Cohesion Policy funds will help Regions implement circular economy strategies, reinforcing their industrial fabric and value chains. The Commission will also harness the potential of EU financing instruments and funds to ensure that all regions benefit from the transition.

As stated by the Commission in CEAP 2020, the transition to a circular economy will be systemic, profound, and transformative. The consequences of such a transition, in some instances, could be destabilising since some regions will face relevant socioeconomic changes. Furthermore, as underlined by the President of the European Commission, Ursula von der Leyen, "the transformation ahead of us is unprecedented. And it will only work if it is just – and if it works for all". The Commission specifies to this extent that "it will require an alignment and cooperation of all stakeholders at all levels EU, national, regional and local, and international".

Accordingly, Italy should have the support of a National circular economy agency, as other countries, not only in Europe, have. Taking advantage of available competencies and structures and collaborating with the various regions, such an organisation could favour correct regulations on by-products, stimulating resources audit and industrial symbiosis. This activity would lead to the implementation an effective integrated resource management system from a circular economy perspective with a coherent approach throughout the country. In this direction, in 2016, ENEA promoted the initiative SUN (Symbiosis Users Network), intending to boost the application of industrial symbiosis in Italy through the involvement of different stakeholders. It is remanded to the facilitator section 4.1 for further analysis.

2.3. Italian

2.3.1. National by-product legislation

The Italian regulation of the by-product is contained in articles 183 and 184-bis of Legislative Decree n. 152/2006 [23]. Article 183, paragraph 1, defines the by product as "any substance or object that satisfies the conditions set out in Article 184 bis, paragraph 1, or which meets the criteria set out following Article 184-bis, paragraph 2". In particular, Article 184-bis, paragraph 2, provides for the possibility, based on the conditions laid down in paragraph 1, to take measures to establish qualitative or quantitative criteria to be met so that specific types of substances or objects are considered by-products and not waste. These criteria are adopted with one or more decrees of the Minister of the Environment.

In 2016 the Ministry of the Environment issued a Decree on 13 October 2016, n.264 [41]. ("Regulation containing indicative criteria to facilitate the demonstration of the existence of the requirements for the qualification of production residues as by-products and not as waste") that entered into force on 2 March 2017. As also specified by the explanatory Circular n. 7619 of 30 May 2017 [42] of the Ministry of the Environment, Decree 264/2016 does not innovate the general discipline of the sector. However, it aims to be a clarification tool available to companies, administrations and supervisory bodies concerning the demonstration of the conditions set up in art. 184 bis.

Furthermore, Ministerial Decree n.264/16, to promote the transfer and sale of by-products, provides for the establishment at the Chambers of Commerce of a public list of by-products in which producers and users can register. Registration in that list does not constitute an enabling requirement but has only a cognitive function, and it aims at mere facilitation of exchanges.

The qualification of a material as a by-product does not depend on the registration of the producer or the user in this list since it is exclusively linked to the demonstration of the conditions laid down in article 184-bis. Finally, since the by-product rules are exceptional and derogate from the ordinary waste rules, the burden of proof concerning the above conditions must be met by those producing the residue and managed as a by-product.

2.3.2. Italy's Recovery and Resilience plan and National Strategy for the Circular Economy

Following an unprecedented crisis due to the pandemic, Italy's recovery and resilience plan responded to the urgent need to foster a strong recovery and prepare Italy's future. The reforms and investments in the program (2.1 billion dedicated to CE) will help Italy become more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions. To this end, the plan consists of 132 investments and 58 reforms.

The reforms address bottlenecks to lasting and sustainable growth, while investments are targeted to foster the digital and green transition and address social and territorial divides. All reforms and assets must be implemented within a tight time frame (August 2026), as the Regulation on the Recovery and Resilience Facility foresees. When designing the plan, Italian authorities consulted national and regional social partners and stakeholders while pursuing a close dialogue with the Commission ahead of the formal submission of the plan on 30 April 2021.

On 22 June 2021, the Commission gave its green light to the plan. President von der Leyen transmitted the Commission's assessment to Prime Minister Draghi during a visit to Rome. The Council adopted the plan on 13 July, opening the door to its implementation. Regarding climate and environmental policies, Italy's improving in managing waste and water resources and strengthening the energy efficiency of buildings.

Italy's new National Strategy for a Circular Economy [40] ("Strategia Nazionale per l'economia circolare") focused on two practices: eco-design and eco-efficiency. Both approaches tackle the beginning of product development. Indeed, to foster their adoption, new administrative and fiscal tools are introduced to strengthen the market of secondary raw materials, extend producer and consumer responsibilities, spread sharing and "product as a service" business model, support the attainment of climate neutrality objectives, and define a roadmap of actions and measurable targets by 2040. The new NSCE will cover eco-design, product innovation, bio-economy, blue economy, and critical raw materials. The following actions and tools are established:

- Devising a new digital waste traceability system to enable, on the one hand, developing a market for secondary raw materials and, on the other hand, enhancing control and prevention of illegal waste management;
- Developing tax incentive systems to support the use of materials from recycling chains;

- Revising the taxation system to make recycling more convenient than landfilling;
- Promoting a right to reuse and repair;
- Reforming the EPR (Extended Producer Responsibility) systems and Consortia to support EU targets;
- Strengthening the existing regulatory instruments (End-of-Waste Legislation, Minimum Environmental Criteria (MEC), and applying them to strategic sectors such as construction, textiles, plastics, WEEE;
- Supporting industrial symbiosis projects, also through regulatory and financial instruments.

3 | Industrial Symbiosis, literature review and concept development

Industrial Symbiosis (IS) is a systems approach that engages diverse organisations in a network to foster eco-innovation and long-term culture change. It leverages underutilised resources (such as materials, energy, water, capacity, expertise, and assets), creating and sharing knowledge through the network. Moreover, IS yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes.

3.1. Concept evolution

The starting point of the reasoning is that people were used to considering the industrial system as a separate entity from the biosphere, with factories and cities on one side and nature on the other. Whereas right now, policymakers and entrepreneurs are trying to minimise the impact of the industrial system. A key question comes from the United Nations conference at the Rio Summit in June 1992: "How can sustainable development be made operational and economically feasible?" The answer is thanks to Industrial Ecology. This thesis's central concept is Industrial Symbiosis, a research subfield of Industrial Ecology.

The following paragraph proposes a brief evolution over time of the concept, which culminates with the Industrial Symbiosis definition. As seen in the figure 3.1, the starting line returns to early 1920.

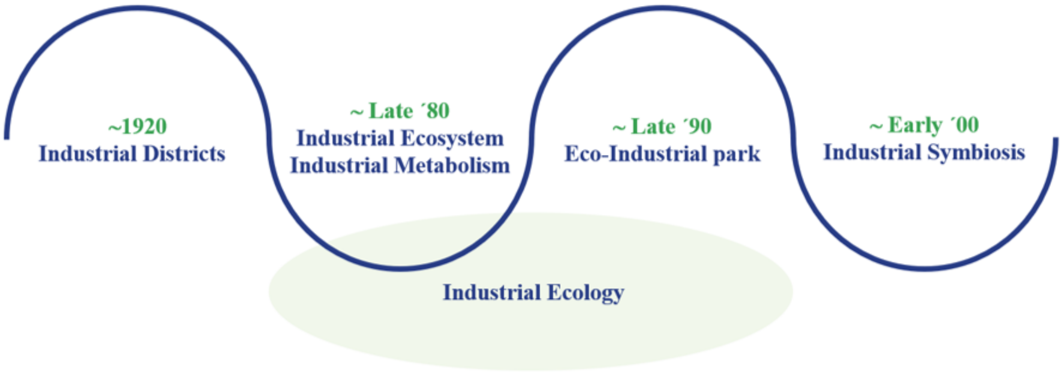


Figure 3.1: Concept evolution

3.1.1. Industrial Districts

The first brick upon Industrial Symbiosis concept was built in the early 1900 with the Industrial District (ID) concept. By examining Britain's leadership in textile production, the economist Alfred Marshall defined ID as "an Industrial District is a place where workers and firms, specialised in the main industry and auxiliary industries, live and work." [38]. A critical aspect that will be further discussed in section 5.1.1 is the impact of the specialisation in only a core industry with its auxiliary partners. This aspect implies a limited differentiation in the surrounding areas.

3.1.2. Industrial Ecology

One step ahead, the academic literature defines Industrial Ecology (IE) [9] as a field of study focused on the stages of the production processes of goods and services from the point of view of nature, trying to mimic a natural system by conserving and reusing resources. With IE, a new system perspective was born; no longer the industrial structure is separated by nature. Three critical elements [24] of the industrial ecology/metabolism perspective are:

- It is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere
- It emphasises the biophysical substratum of human activities, i.e., the complex patterns of material flow within and outside the industrial system, in contrast with current approaches, which most consider the economy in terms of abstract monetary units, or energy flows
- It considers technological dynamics, i.e., the long-term evolution (technological tra-

jectories) of clusters of critical technologies, as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem

Industrial Ecology can be seen as an umbrella concept nested under several research paths had been ensued.

Industrial Ecosystem

In 1989, Frosch & Gallopoulos [31] were inspired by the IE thesis. Indeed, they wrote about the "Industrial Ecosystem"; "the consumption of energy and materials is optimised, and the effluents of one process serve as the raw material for another".

Industrial Metabolism

In the same year, 1989, Ayres [4] wrote about both the biosphere and the industrial economy "as systems for the transformation of materials" and how studying this Industrial Metabolism could lead to shifts in the direction of increased efficiency in materials flows and waste streams.

3.1.3. Eco-Industrial Park

According to the President of the Council on Sustainable Development, an Eco-Industrial Park is "a community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, water, energy, infrastructure and natural habitat), leading to economic gains, gains in environmental quality, and equitable enhancement of human resources for the business and local community" [14].

While according to the EPA Fieldbook, an Eco-Industrial Park is "a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water, and materials. By working together, the community of businesses seeks a collective benefit greater than the sum of the individual benefits each company would realise if it optimised its performance only".

Lowe et al. [20] encourage a broad view of eco-industrial parks and go on to say, in a briefing and sourcebook on industrial ecology, that an eco-industrial park should be more than:

1. A single by-product exchange pattern or network of exchanges
2. A recycling business cluster (resource recovery or recycling companies)
3. A collection of environmental technology companies
4. A group of companies making green products
5. An industrial park designed around a single environmental theme (i.e., a solar energy-driven park)
6. A park with environmentally friendly infrastructure or construction
7. A mixed-use development (industrial, commercial, and residential)

At this early stage, the environment is not served by overly prescriptive determinations of what is and is not an eco-industrial park.

3.2. Sustainable Development

To further complete and better understand this evolutionary path is necessary to introduce and complete it with two other fundamental concepts.

The concept of sustainability, as known today, was introduced in 1987. The Brundtland report [6] saying: "Sustainable development is a development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs". This definition exposes the requisite for inter and intra-generation equity and focuses on two keywords:

- The concept of needs. In particular, the basic needs of the whole population (food, shelter, health, education, clothing), to which overhang priority should be given
- The idea of limitation imposed by the state of technology and social organisation on the environment's ability to meet present and future needs

To achieve sustainable development is needed [10] that:

- The withdrawal levels of non-renewable resources do not exceed their regenerative capacity. Meanwhile, the emission of waste (solid, liquid, and gaseous) does not exceed the assimilation capacity of the natural systems

- Technology's progress to produce goods and services is directed towards increasing efficiency rather than increasing the flow of energy and raw materials
- Human intervention is limited within the carrying capacity of natural systems while preserving their vitality and resilience

Nested under the SD concept, several research paths have started, such as Regenerative Design, Cradle-to-Cradle, Performance Economy, Industrial Economy, Biomimicry, Blue Economy, and Industrial Ecology. For this Thesis purpose, only Industrial Ecology was explained.

3.2.1. Circular Economy

The last preliminary concept to be introduced is the Circular Economy (CE), which could be seen as an operational approach to Sustainable Development. The most diffuse and recognised definition of CE is the one proposed by the Ellen MacArthur Foundation [37]: "Circular economy is an industrial economy that is restorative or regenerative by intention and design". A circular economy business model is founded on five principles:

- Design out waste and pollution. Waste does not exist when a product's biological and technical components (or "nutrients") are designed to fit within a biological or technical materials cycle. Move from pollution control to pollution prevention by intention and design.
- Keep products and materials in use through reuse, repair, remanufacturing, and recycling.
- Regenerate natural system. Avoid the use of non-renewable resources and preserve or enhance renewable ones.
- Think in systems. The ability to understand how parts influence one another is crucial.
- Waste is food. On the biological side, the ability to reintroduce products and materials back into the biosphere through non-toxic, restorative loops is at the heart of the idea. On the technical nutrients side, improvements in quality are also possible, and this is the so-called upcycling.

3.3. Industrial Symbiosis

Concerning the sustainability literature, researchers of regional socioeconomic systems have hypothesised that the transition from unsustainable to sustainable is an evolutionary process most likely to be introduced at the local level. Like biological evolution, these "islands of sustainability" are thought to move toward higher circulation rates of materials within the system and increase the total solar energy flux. Industrial symbiosis is cited in this literature as one of the evolutionary paths toward higher diversity and complexity of regional strategies. This economics literature has long considered the effect of proximity to significant inputs and transportation costs in determining business location decisions and the resulting spatial pattern of development. However, it has yet to evaluate the impact that strategic colocation of facilities with complementary input/output needs can have on locational advantage. Those two previous notions will be further discussed in this paragraph because they represent the criticalities of an IS success case and not only a potential one. Moreover, Industrial Symbiosis allows local communities to coexist harmoniously with the industrial systems without sacrificing people's quality of life. It generates a virtuous interaction between companies and the territory that simultaneously promotes competitiveness, innovation and employment and protects ecosystems and biodiversity.

3.3.1. Definitions

The part of industrial ecology known as industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving a physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity. By working together, businesses strive for a collective benefit more significant than the sum of individual benefits that could be achieved by acting alone. Eco-industrial parks are examined as concrete realisations of the industrial symbiosis concept. Industrial ecology, as seen, allows focus at the facility, inter-firm, and regional or global levels. IS can be positioned at the inter-firm level because it includes exchange options among several organisations. The expression "symbiosis" is inspired by symbiotic biological relationships in nature, in which at least two otherwise unrelated species exchange materials, energy, or information mutually beneficially. This specific type of symbiosis is known as mutualism.

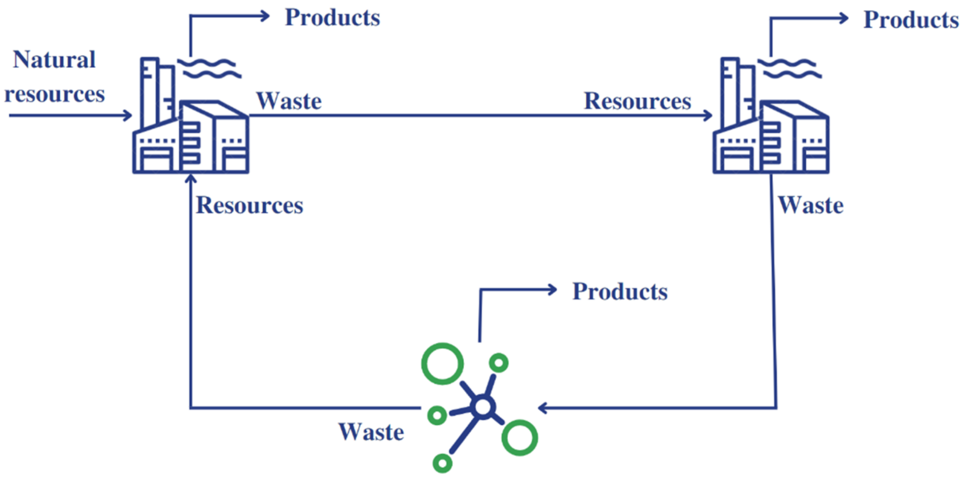


Figure 3.2: Industrial symbiosis graphical representation

The very first term of industrial symbiosis was coined by the power station manager in Kalundborg, meaning "a cooperation between different industries by which the presence of each increases the viability of the other(s), and by which the demands of society for resource savings and environmental protection are considered". For deepening the Kalundborg case, section 3.5.

The first scholar to dedicate an intense study of the IS concept was Chertow. She said that "the part of industrial ecology known as industrial symbiosis engages traditionally different industries in a collective approach to competitive advantage involving the physical exchange of materials, energy, water, and by-products" [7]. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.

Chertow's definition date back to 2000; some years later, in 2006, Laybourn [34] defines "Industrial Symbiosis as a network that engages diverse organisations to foster eco-innovation and long-term culture change. They are creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes".

There are structural differences between the two academic definitions and how the concept evolved over the years. IS is not essentially localised waste and by-product exchanges, nor should it be confused with agglomeration economies or industrial clusters where geographic proximity is necessary. Indeed, geographical proximity is explicitly negated [36] in favour of one that is rooted in innovation and networks for knowledge sharing, resulting in, but not driven by, improved efficiency in the use of materials.

The diversity of terminology within the IS sphere and all the research cited in the previous paragraphs can generate confusion. The lack of a standardised and internationally accepted methodology for identifying industrial symbiosis push scholars to formulate some elements which are considered vital in characterising industrial symbiosis [50]:

- IS may involve different industry actors belonging to various sectors of activity. As with Porter's cluster theory, it also involves governmental and other institutions, including universities and trade associations.
- IS may involve transactions not only of material resources but also energy and water, and other resources such as space, knowledge, expertise, capacity, and logistics.
- IS involves a systemic view of how industrial systems work.
- IS includes bilateral (organisation to organisation) and multilateral (multiple organisations involved) transactions.
- Transactions may happen within the boundaries of the network or beyond them and may involve both current network members and new participants (the main criteria being the valorisation of the resources)
- These transactions can be assimilated in most, if not all, cases to market transactions. It is hypothesised that, in some cases, they may transcend mere market exchange and involve different degrees of cooperation.
- The collaboration potential is identified through networking, whereby stakeholders interact to find mutually beneficial solutions.
- The environmental and economic outcomes may surpass the results that the individual organisations would obtain by acting individually, so there is an additional benefit associated with the collaboration.
- Resources, water, and energy may be optimised through cooperation, which goes hand in hand with reducing the environmental impacts of the IS participants' activities.
- Generally, IS participants prioritise the improvement of economic impacts or profitability in their organisation to justify their participation in IS.

To conclude is proposed a "working" definition. Industrial symbiosis encompasses networks of different industrial actors belonging to various sectors of activity that, by collaboration and networking, identify opportunities to keep physical resources in productive use for longer (rather than go to waste). Thereby they can achieve a better system performance in using resources (including materials, energy, water, technology, and knowledge), resulting in beneficial environmental and economic outcomes. In some cases, physical resource transactions also involve expertise and knowledge transfer. It is also important to note that transactions of one type of resource may trigger collaboration in other areas involving other resources. Learning and transaction costs may be reduced and further opportunities identified.

3.4. Taxonomy

It is helpful to propose a taxonomy distinguishing different eco-industrial park models to organise the Italian IS case mapping presented in chapter 4. In the Thesis is presented and adopted Chertow's Taxonomy [7]. Chertow, following a detailed study of 18 potential eco-industrial parks examined at the Yale School of Forestry and Environmental Studies from 1997 to 1999, proposed five different material exchange types. These are discussed here as Types 1–5, listed below:

- Type 1: through waste exchanges
- Type 2: within a facility, firm, or organisation
- Type 3: among firms colocated in a defined eco-industrial park
- Type 4: among local firms that are not colocated
- Type 5: among firms organised "virtually" across a broader region

By definition, Types 3–5 offer approaches that can readily be identified as Industrial Symbiosis.

3.4.1. Type 1

In those cases, businesses recycle and donate or sell recovered materials through third-party brokers and dealers to other organisations. Type 1 exchanges are not further examined because they are farthest from the definition of industrial symbiosis. These exchanges typically involve older, more traditional aspects of the material flow landscape.

3.4.2. Type 2

Some material exchange can occur primarily inside the boundaries, between different business units of the same organisation, rather than with a collection of outside parties. Large organisations often behave as separate entities and may approximate a multi-firm approach to industrial symbiosis.

3.4.3. Type 3

In this approach, businesses and other organisations located in the equivalent of an industrial park can exchange energy, water, and materials and can go further to share information and services such as permitting, transportation, and marketing. Type 3 exchanges primarily occur within the defined area of the industrial park, but it is possible to involve other partners "over the fence." The sites can be new developments or retrofits of existing ones.

3.4.4. Type 4

This type of exchange takes what is already in place within an area as a starting point, linking existing businesses with the opportunity to fill in some new ones. Kalundborg, the most well-known case and examined in section 3.5, is an example of a Type 4 exchange at its early stage, primary partners are not contiguous but within about a two-mile radius. Although this area was not planned as an industrial park, the companies' proximity allowed them to take advantage of already generated material, water, and energy streams, and later becoming an Eco-Industrial park.

3.4.5. Type 5

Given the high cost of moving and other critical variables that enter into decisions about corporate location, very few businesses will relocate solely to be part of industrial symbiosis. In recognition of this, the model of Type 5 exchanges depends on virtual linkages rather than colocation. Some examples of virtual exchanges are knowledge, information, and technology.

3.5. The first and still one the best case of IS - Kalundborg

The model of Industrial Symbiosis was first fully realised in the eco-industrial park at Kalundborg, Denmark. The history of Kalundborg began in 1961 with a project to use surface water from Lake Tissø for a new oil refinery to save the limited groundwater supplies. The city of Kalundborg was responsible for building the pipeline while the refinery financed it. Many other collaborative projects were introduced starting from this initial collaboration, and the number of partners gradually increased. By the end of the 1980s, the partners realised that they had effectively "self-organised" into what is probably the best-known example of a working industrial ecosystem.

The status of the industrial symbiosis in 1999 is shown in Figure 3.3. From this diagram, it can be appreciated how extensive the collaboration regarding materials and energy is.

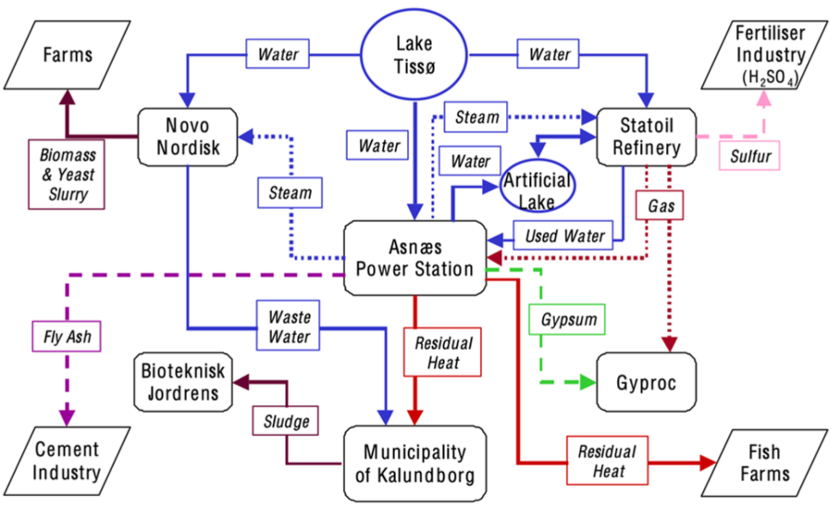


Figure 3.3: Material Flows in the Kalundbord Industrial Ecosystem [11]

The ecosystem today consists of fourteen public and a private company; the six main partners are:

- Asnæs power station. It is part of SK Power Company and Denmark's most considerable coal-fired plant producing electricity.
- Statoil. It is an oil refinery belonging to the Norwegian State oil company.
- Novo Nordisk. A multi-national biotechnology company that is the largest producer of insulin and industrial enzymes.

- Gyproc. Swedish company producing plasterboard for the building industry.
- The town of Kalundborg receives excess heat from Asnaes for its residential district heating system.
- Bioteknisk Jordrens - a soil remediation company that joined the eco-park in 1998.

3.5.1. Material and Energy flow - 1999 Analysis

It is essential to point out that water is a scarce resource in this part of Denmark, and the collaboration aimed to valorise it. As mentioned above, to reduce groundwater consumption, Lake Tissø has become the primary water source for the industrial partners in Kalundborg. The reduction in groundwater use has been estimated at close to 2 million cubic metres per year. However, to further reduce overall water consumption by the partners, the Statoil refinery supplies its purified wastewater and its used cooling water to Asnæs power station. Thus, allowing this water to be "used twice" and saving an additional 1 million cubic metres of water per year.

Excess gas from the operations at the Statoil refinery is treated to remove sulfur, which is sold as a raw material to manufacture sulfuric acid. The clean gas is then supplied to Asnæs power station and Gyproc as an energy source. Asnæs power station provides steam to Statoil and Novo Nordisk for heating their processes. The power station can increase its efficiency by functioning in a co-generation mode.

In 1993 Asnæs power station installed a desulphurisation unit to remove sulfur from its flue gases, which allowed it to produce calcium sulfate (gypsum), the primary raw material in manufacturing plasterboard at Gyproc. By purchasing synthetic "waste" gypsum from Asnæs power station, Gyproc has been able to replace the natural gypsum that it used to buy from Spain. In 1998 approximately 190,000 tons per year of synthetic gypsum were available from the power station. Novo Nordisk creates a large quantity of used bio-mass from its synthetic processes. The company has realised that this can be used as a fertiliser since it contains nitrogen, phosphorus and potassium. The local farming communities use more than 800,000 cubic metres of this liquid fertiliser each year and over 60,000 tons of a solid form of the fertiliser.

Finally, residual heat is also provided by Asnæs power station to the district heating system of the town. The system functions via heat exchangers so that the industrial and district heating water is kept separate.

Reduction in consumption of resources	
oil	45,000 tons/year
coal	15,000 tons/year
water	600,000 m^3/year
Reduction in waste emission	
carbon dioxide	175,000 tons/year
sulfur dioxide	10,200 tons/year
Valorisation of wastes	
sulfur	4,500 tons/year
calcium sulfate (gypsum)	90,000 tons/year
fly ash (for cement)	130,000 m^3/year

Table 3.1: Environmental Aspect of the Symbiosis [25]

4 | Italian findings

After the economic and environmental introduction, chapter 1, the Normative and Legislation influence, chapter 2, and the definition of the Industrial Symbiosis concept, chapter 3. This chapter proposed a map of the Italian IS cases, findings and insight from the working field. Starting from describing materials and methods used to perform the analysis, it follows a visual map of the cases analysed. It concludes with a description of some notable cases and interviews. Moreover, findings, outcomes, and respondents' suggestions will be linked and further explored with the IS Strategy presented in chapter 5.

4.0.1. Materials and Method

This brief section explains the materials and methods adopted to gather all the information provided in this chapter. Firstly, literature review was performed to grasp the magnitude of the finding. The goal was to collect all the cases of IS analysis. Scholars subdivide the investigation into actual and potential IS cases. The former is a real case in the market, while the latter are studies concerning the chemical and strategic implications of potential IS; those cases will not be included in the map proposed in the following section.

The starting 102 papers have formed a pool of 35 searchers with IS, and potential IS cases analysed; among them, only 18 contain real IS cases. Other 67 articles tackling the strategic implication of IS (e.g., strategies, barriers, opportunities) have been used to assess the analysis to overcome IS barriers. Keywords used to perform the preliminary research were: Industrial Symbiosis, Circular Economy practices, Industrial park, and Eco-Industrial park.

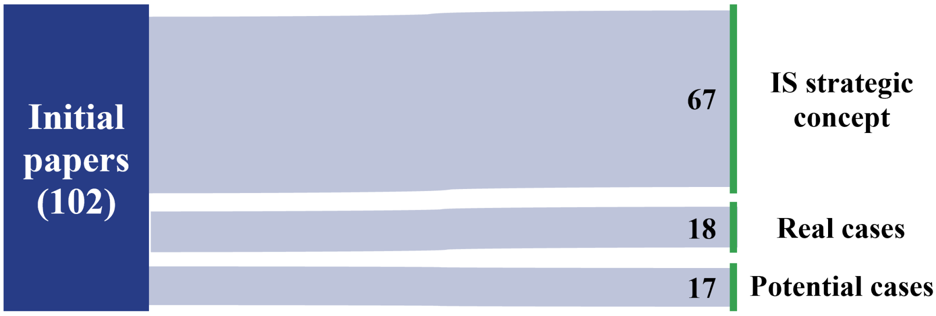


Figure 4.1: Literature review papers pool

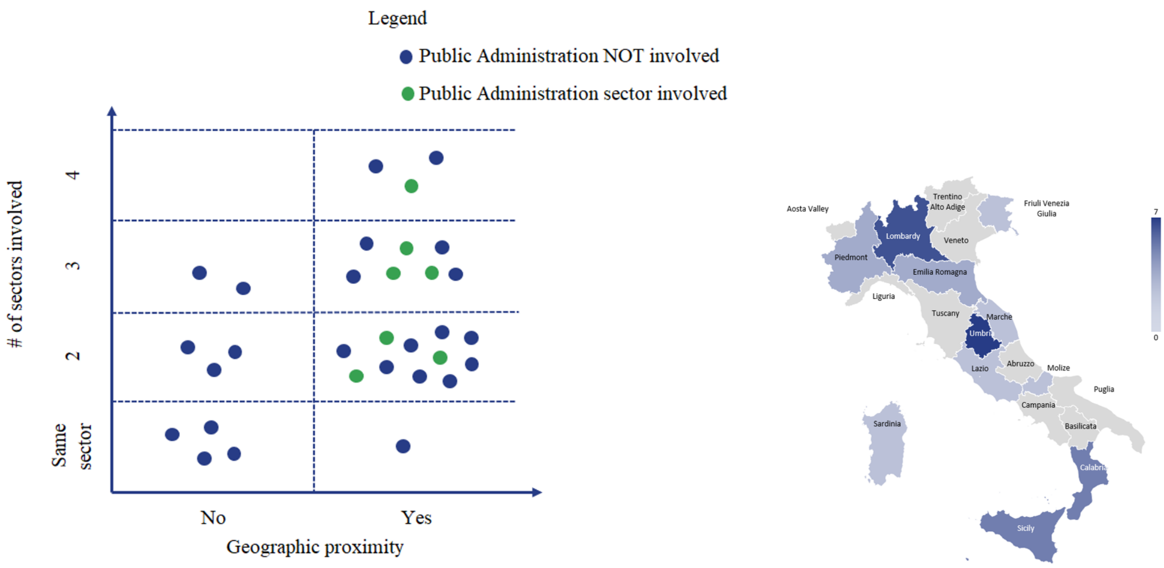
To further ample the cases scrutinised, websites and databases were consulted. Once all the worthed cases were analysed, a database was constructed. The structure of it helps in subdividing the investigation according to a specific taxonomy, sectors involved, where is located the IS case, companies involved, their contacts and further info. As soon as the database was complete, two different activity has been done in parallel. The first was contacting all the companies involved and SUN's project references. The second one was building a map and analysing the data found.

The most used websites and databases were Scopus, Google Scholar, Statista, SUN network, and sites for specific fields.

4.0.2. Italian Industrial Symbiosis map

The map proposed, image 4.2a, works on two axes. The former (x) means if the IS case has a distance between the partners less than $\approx$ 30km. The latter (y) represents the number of sectors involved; in this case, the willingness is to count only the industries and not how many players are implicated.

The first theme that needs to be discussed is geographic proximity. According to the definitions proposed is not a relevant driver, while the Italian context shows a different concern. Indeed, among the 31 Italian cases found, 71% of the cases work in proximity. Moreover, if the space has limited, a partnership with the Public Administration is desired and sometimes achieved. While in the case of no geographic proximity, collaboration with the Municipality is hard to accomplish and not founded in the study.



(a) Sectors involved. (b) Italian distribution.

Figure 4.2: Italian geograpic proximity and cases in Italy.

Those cases are positioned on the Italian map as shown in the figure 4.2b. This picture clearly shows an external and positive influence. In this regard, the projects proposed by the Italian Symbiosis Users Network (SUN) positively spread the IS theme. For further information is remanded to the Facilitators section 4.1.

The matrix clearly shows that the higher population belongs to the quadrant "two sectors with geographic proximity", with 12 cases out of 31. The most common interaction within this quadrant happens between the agri-food sector and the chemical-pharmaceutical one (33% of the cases). Other exchanges are shown in the sankey chart, figure 4.3.

Figure 4.3: Two sectors with geographic proximity interactions

Some notable examples of interaction starts from the sugar cane, almond, or grape (agri-food wastes). The company that receives in input that kind of leftover can produce food supplements or beauty products. While concerning Public Administration involvement, everyday transactions are wastewater management and more general waste management to produce energy (Waste to Energy).

According to the research finding, four sectors is the highest score. Even if it could be seen as a good result, a large room for improvement can be made; this is due mainly to the complete absence of the case of the eco-industrial park, as shown in the following matrix, which shows types of Industrial Symbiosis are according to the taxonomy proposed.

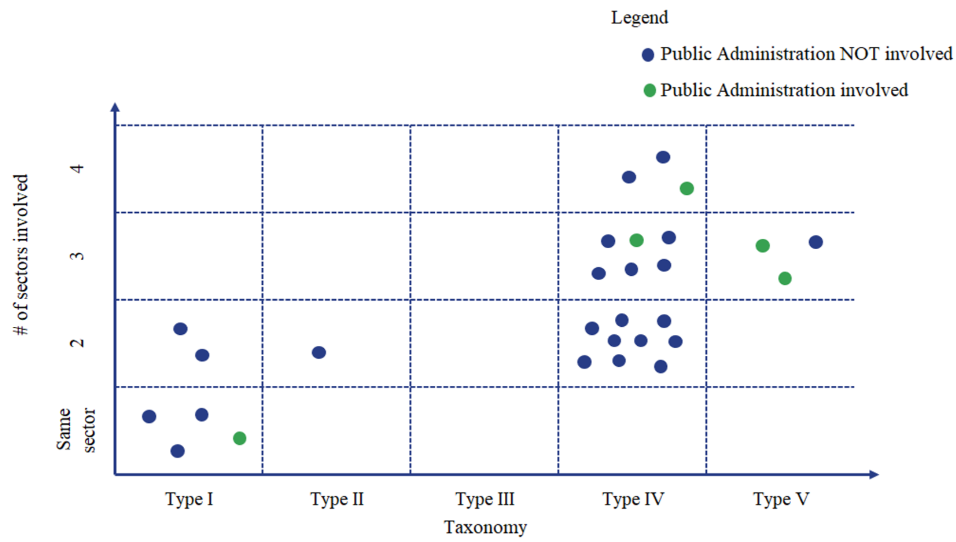


Figure 4.4: Italian IS cases classified

- Type I Italian cases show the presence of the core firm that buys secondary hand raw materials (already recycled) or wastes from consortia, waste unions, or many small firms to produce a new product which contains a quota of recycled material.
- Type II is present in only one case. As seen in the taxonomy, one firm shares leftovers or sub-products among its business units within its boundaries. One possible reason for this low discovery number is that firms are unaware of IS practice. Thus, they still do not disclose this information in their sustainability report.
- Type IV, the most populated case, is also called the base case of IS. Firms, by building a network, start to collaborate to reduce waste and with the willingness to keep the value within the circle of the sub-component.
- Lastly, in the type V case, a central authority (usually a platform) divulges and discloses new technologies and business models that can link the demand and offer from different firms even over an extended geographical distance.

The complete absence of Type III, the Eco-Industrial park, directly implies the narrowness of the sectors involved. Looking at some of the best EU cases of Eco-Industrial parks, such as the Kalundborg in Denmark, the Händelö in Sweden, and the Ökopark Erlebnisreich in Austria, all of them are working in partnership with the third sectors and several partners among different industries.

4.0.3. Some notable examples

This section presents some notable cases by following the taxonomy adopted.

Type 1

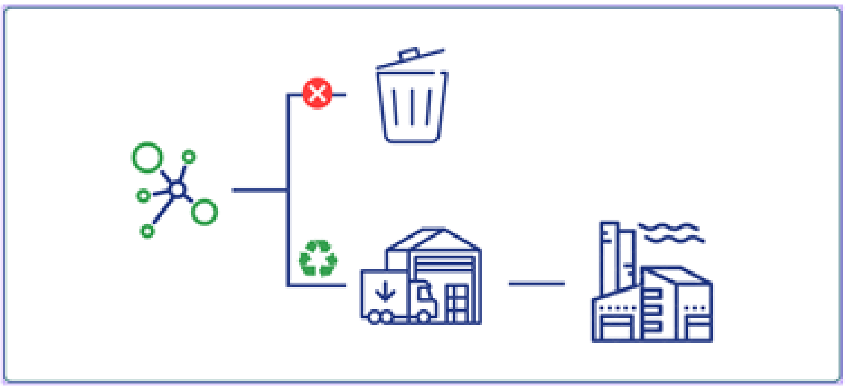


Figure 4.5: Type 1 IS graphical representation. From recycled plastic to a new circular wall.

This specific case shows how consortia play a pivotal role in collecting plastic waste to recycle it properly. The firm, starting from the plastic reverve supply chain, uses PET as secondary raw material to build a "circular wall". Using recycled plastic, the company can reduce the polystyrene foam commonly used as virgin raw material. The new product can be used in industrial and commercial pre-fabricated structures. The benefits for the company are: easy to produce at an equal cost, which is crucial because second-hand raw materials still cost more than virgin ones, and the reliability of the wall is similar to one produced with complete pure material. The main benefit for the stakeholders is that plastic waste is being reused.

Type 2

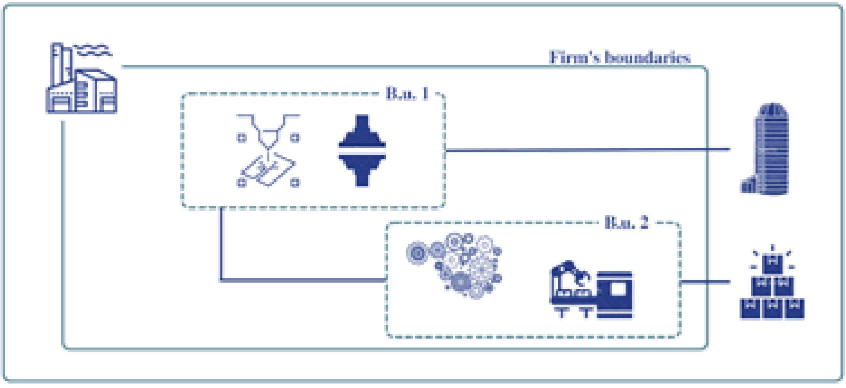


Figure 4.6: Type 2 IS graphical representation. Leftovers used within the company's boundaries.

As seen by the graphical representation of the case, sub-components are transferred between two different BU within the company's boundaries. In this case, the core products are silos and tanks; in the production phase, metal sheets may be wasted due to the laser cut and press bending operations. The firm can use that leftover to produce new stationery products in metal design, such as pens, book holders, and office laps. The primary benefit of adopting Industrial Symbiosis is the reduction of waste produced. Furthermore, they open up to a new source of revenues coming from a second and fresh market.

Type 4

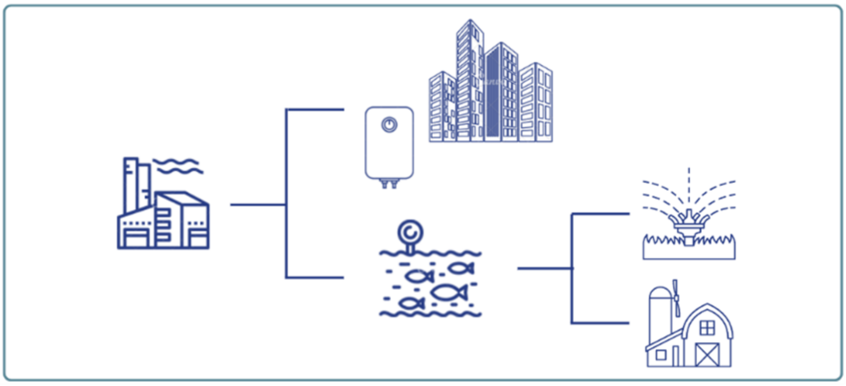


Figure 4.7: Type 4 IS graphical representation. An Italian case of a IS district.

This honourable case belongs to IS Type 4. The leading player is a steel producer that was able to reuse its cooling water from the production process to supply the adjacent

Municipalities and a seafood farm (specifically a sturgeon farm to collect caviar). Also, once the water loses all its thermal energy, it is used again to supply surroundings farms; not only, but seafood farm leftovers are used to produce compost. This example shows how different realities can cooperate to be more sustainable and not lose any value in the supply chain. More cases like this would be more than welcome. Indeed, with correct planning, firms belonging to entirely different industries can have a mutual benefit in the collaboration, thus becoming cases of Eco-Industrial parks.

Type 5

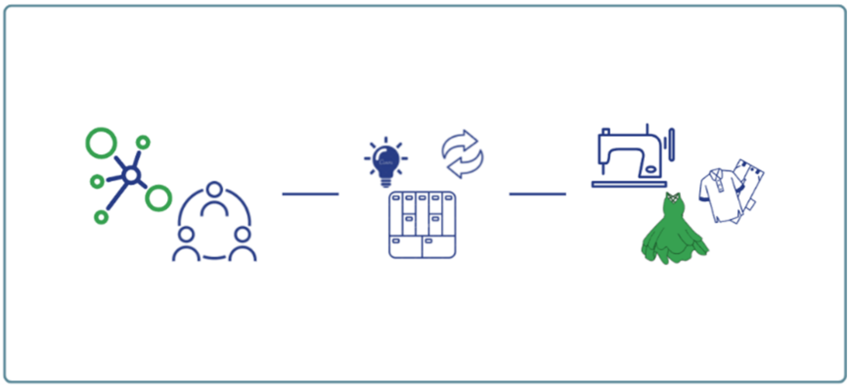


Figure 4.8: Type 5 IS graphical representation. This case shows how a platform can diffuse IS business model.

This last example belongs to the apparel industry, one of the most energy and resource-consuming sector. The firm is pivotal in leveraging its knowledge and know-how by acting as a central platform. Specifically, disclosing new business models and helping firms build new operations capabilities is able to link the offer and demand. Due to low quality, old clothes or unused textiles are remitted in the production flow through repair activity or new production. In this case, leftovers or old products are upcycled, meaning their value increase.

4.1. Facilitators

Thanks to the Circular Economy Package adopted by the EU Parliament in the last few years, many large corporations are starting to adopt resource efficiency, eco-innovation and circular economy as critical principles for their strategies. On the other hand, SMEs, which represent 99% of all businesses in the EU and account for 85% of new jobs created over the last years [26, 27], are experiencing more difficulties in adopting such strategies due to their more limited organisational, technological and financial capacity, less access to financing and knowledge. These limits could limit the speed at which Europe can transit toward a more circular economy.

If entities can support and facilitate existing on-site cases of industrial symbiosis, these can also act as enablers for creating new connections. This role can be played either by public entities such as local governments or private entities such as business associations [19, 46]. These entities, which are aware of the reality of the site, can more easily identify new partners for infrastructure sharing and joint provision of services, as well as new companies that may be able to use waste that is not yet in use or that, can provide waste to companies already involved in industrial symbiosis. Challenges are principally rooted in the initiation phase. The initiation of the regional industrial symbiosis consists of several steps, such as mapping the potentials, creating trust among businesses and provision of incentives [44]. Local authorities usually undertake these steps, public research institutes, industrial associations or maybe by a combination of them which are referred to as the facilitator organisation or even by a leading local business. This organisation has to encounter the followings problems:

- Policy development to shift from the linear economy to the circular economy
- The leadership and investments of the private sector
- The culture of collaboration between industries and research institutes
- The flow of information to increase the stakeholders' awareness

However, in places where no synergy networks have been established, the role of these facilitators can be highly relevant. They can provide company training, facilitate the exchange of information, foster cooperation and trust between companies, and coordinate and help identify possible symbiosis relationships.

4.1.1. Italian case

Looking at the Italian context, several players are helping the IS pervasive diffusion. The core player is ENEA. It is the National Agency for New Technologies, Energy and Sustainable Economic Development, a public body aimed at research, technological innovation and providing advanced services to enterprises, public administration and citizens. It aims to improve efficiency in energy, environment and sustainable economic development. SUN is the Symbiosis User Network which promotes circular economy models through industrial symbiosis. It deepens operative issues, which can involve, for example, Legislation, standards, market conditions and good practices. Currently, in April 2020, SUN has 38 partners among universities, political institutions, research centres, private companies, technology networks, and local authorities, and it is open to collecting new partners. Moreover, as seen in the Italian map, SUN projects performed had a positive impacting in diffusing IS actions.

4.1.2. Denmark case

From 2013 to 2015, Denmark set up a database and a matchmaking service to facilitate symbiosis initiatives. The Danish Government funded the project "Less waste using Industrial Symbiosis" and involved five Regions. Two were the main actions realised: a national web database (GIS, Green Industrial Symbiosis) and the establishment of a Task Force providing free advice. By the end of the project period, more than 750 companies were registered in the database. The advisers visited 516 companies to help clarify their resource flow and map their waste and need for resources. One hundred seventy-four companies matched their condition with another company as a first step to signing an industrial symbiosis agreement. It is miserable to point out that despite the positive results, the initiative stopped when the initial subsidy ran out.

4.2. Interviews

This central chapter is concluded with some of the interviews directed. The interview structure was subdivided into catching insights from two macro-themes, Industrial Symbiosis (and CE more in general) and Sustainable Development. Examples of the questions proposed are presented in the Appendix A.

4.2.1. Interview 1 - Steel production industry

The firm is a leader in the electric arc furnace (EAF) steel-making process. The EAF is a batch melting process which produces batches of liquid steel (LS) known as heats. The tap-to-tap cycle of the EAF is made up of several steps consisting of (i) furnace charging, (ii) melting, (iii) refining, (iv) de-slagging, (v) tapping, and (vi) furnace turn-around.

The company thanks to a solid commitment to being one of the first green steel-produced launched more than 20 years ago, the 0-Waste program. The project aims to reduce the leftovers of the production process, which are the white slag coming from the de-slagging phase and the black slag, which is all the material that does not fall out of the ladle. It is essential to point out that the production process is inherently circular because the input material is steel scrap, but it still has some waste. The white slag is rich in calcium, thus, is sold as a product as all the competitors do. The innovation comes from the black slag, whose chemical characteristics are similar to melting rocks and basalt. Through a research partnership with the road Authority start testing if it can be used to produce asphalt. The new sub-product is an EU-registered green one, on which an LCA was conducted to achieve the standard. Right now, it is used as a new input (more or less 25/30%) in the mix of the asphalt production process. Benefits are not only the reduction of CO2e and waste (from company point of view), but also asphalt has doubled its usury.

A follow-up question was whether a strong partnership might be achieved with an asphalt product in an Eco-industrial. Does a feasibility study have been done? Answer: Even if the new product has a good impact on the initial mix, some companies are not ready to pay the green-premium price; it is more convenient to use virgin material. Moreover, one steel production plan can serve $\approx$20 asphalt producers, and a specific aspect of the asphalt production process limits the feasibility, which is that the bituminous product needs to be knocked down for one hour and a half before being pose on the road. This aspect implies the capillarity of the asphalt producers. Thus, no one wants to be closer to the steel producer plant but isolated to the high roads.

Projects to recover thermal energy are on the R&D agenda but are still in progress. In one of the examples proposed is seen how a steel producer can recover its thermal water to further purposes. The company is not supplying the surrounding Municipality being far from them. In contrast, other plants from do (e.g., centre Italy and south Italy plants).

This case of IS shows the property and C-Level commitment to being more sustainable. Indeed, Industrial Symbiosis happens "naturally" as a good management practice. The firm continuously improves its performance by setting new goals. Metrics and KPIs are still taken from past performances avoiding SDGs targets and GRI.

Lastly, which lever might foster IS diffusion? Answer: Recognise the circularity rate at the whole supply chain and not only to the focal player, as cooperation is crucial in diffusing Circular Economy practices.

4.2.2. Interview 2 - BugsLife

BugsLife is a bug farm start-up with the mission to supply pet food producers and thus reduce good food usage in their production process. Their business model can be pivotal in contrasting people's hunger (SDG number 2). Indeed, by entering the lowest level of the food waste hierarchy, collecting wastes from other agri-food industries can feed their flies. Specifically, the firm collects wastes from oil and beer production, the primary ingredients of flies' diet. The business model is entirely replicable by changing the waste input, as soldier flies can be fed by "everything." This case of Industrial Symbiosis is innate because using agri-food leftovers is the starting point to be economically sustainable and pursue a CE approach.

Which are the benefits of having a bug farm? Answer: As said, the goal is to change the actual input of pet food. Soldier fly larvas are ground to produce a flower with high protein organoleptic proprieties; during the process also, bugs' oil is created, which is also used to feed animals. The production plant can be tiny, like 2,000 m^2, with an assimilation capacity of 15,000 tons per year so that it can be installed near every agri-food processor. The only waste is adult corpses needed to keep the life cycle of the farm, but also this can be used to generate biogas and thus energy. To extend this last consequence, the entrepreneur argued that Nations like France, Portugal, and not only are highly investing in this field of a sustainable and strategic energy source.

How policies and laws are influencing the bugs industries? Answer: Right now, only eight insects can be used as Human food sources. Soldier flies are not listed because they are used as waste processors. A huge behaviour barrier needs to be broken because people are not ready to eat insects, even if they produce high-quality protein. To further explore this reasoning, it is required to be realistic and critical; those production processes are far from optimised; indeed, typical protein fonts such as chicken and fish are still more economical, so bugs are the perfect solution. Also, from an LCA point of view, both authorised insects and familiar protein sources use good food (high level in the food waste hierarchy) that can be used to feed Humans. This way, the whole supply chain adds a new link (extra energy and resource usage) that can be avoided. To conclude this digression, Giacomo, one of the founders, point out that their aim is not to substitute or disrupt the actual food supply chain but to keep high-level food quality for Human, and not for pets, but use their product to feed them.

Lastly, which difficulties did you find in applying your business model? Answer: Even if feeding bugs require only waste, a vast bureaucracy needs to be accomplished. An ASL permit must be achieved to guarantee the traceability of the product, which is acceptable;

the problem is the lengthy process. A possible way to solve this problem is to build a complete insect and insect-food norm.

4.2.3. Interview 3 - Molhelix

Molhelix is helicicolture start up. The two entrepreneurs' mission is to show the feasibility of a Circular Economy business model and, even with many difficulties, how many benefits can bring to the soil. Hens are fed with large-scale food supply distribution leftover. Even in this case, like the previous one, Industrial Symbiosis is innate in the business model. The success of Molhelix brought lots of attention in the surrounding area, becoming an elementary and medium school case study in which young students are taught basic principles of Circular Economy and how to apply them in their daily life.

The inspirational discussion with the startupper brought to light the effort an entrepreneur must have to pass through all the regulations and laws present in Italy. Some examples are listed:

- An Helicicolture farm must have 40% of its area dedicated to a vegetable farm. This Regulation may be removed because if a farmhouse can sustain the hens' diet with other businesses, why an area restriction is imposed?
- Even in this case, an ASL permit must be achieved to operate
- In this case, the large-scale food supply distribution partner had to include a new juridical business unit responsible for being an animal food supplier. As mentioned in the company profile, the mission was to follow and show the complete path, even if not economically beneficial (the two founders are academic researchers). To further explore this point, having a partner with a higher bargaining power may avoid this possible cooperation. Other realities avoid this last aspect by directly selling fruit and vegetable waste to helicicolture or another animal farm.

Do you agree that policy intervention is the lever most important? What would you change to make IS and CE more pervasive? Answer: from a start-up point of view, some certifications should be made ex-post once the business model is tested and see that it is economically sustainable. The legislation start-up playground usually is a grey zone with a lack of normative or too much stringent. An ex-ante audit can limit the testing, and virtuous business cases may not be experienced.

4.2.4. Interview 4 - Bakery producer

The company partnered with the "Mediterranea" University of Reggio Calabria three years ago, launched the "bakery food" project. The goal was to seek new bakery products that increased organoleptic proprieties and input variants. One of the studies conducted was with beer leftovers (thresher); its characteristics increased the fibre in the final product. This new input permits the company to reduce the cost of virgin flour, which is increased due to the tension between Ukraine and Russia. Indeed, further feasibility studies on other products are in place.

How did you build the network? Answer: Threshers can generally be bought in the market, but the willingness was to construct a close partnership and, thus, an Industrial Symbiosis. The partner chosen is an alcohol producer, which is close to the production plants. Geographical proximity was crucial because lots of research and testing have been done.

Which aspect could be helpful to push more cases like yours? Answer: Firstly, speaking about the agri-food industry, it is not only about finding new recipes. They must be reliable for health safety and have a positive economic impact. Furthermore, the "bakery food" project has regional financial incentives only for discovering new products from the theoretical point of view. Thus, incentives should follow from the development to the realisation of the product. The firm has also invested in making it feasible, developing a new production line and a new hoven to cook the threshers.

Which lever would you suggest? Answer: The firm experiences a lack of a central authority that can link companies with a specific waste to those willing to use it. A mandatory and public waste register might solve this problem. The economic sphere is still the most relevant. Thus tax relief on sustainable R&D initiatives and real cases is mandatory.

4.2.5. Interview 5 - Manufacturing industry

The company is a world-leading professional coffee machine producer. Their presence at open innovation round tables and university and regional discussion meetings foster their awareness of CE and SD concepts. This symbiosis case starts from a solid top-manager commitment to cooperate. The actualisation of the partnership comes thanks to the MARLIC project, which is one of the SUN and ENEA running projects. The firm can recover the materials from metal sheets and sinks leftovers through a demanufacturing approach.

Which kind of benefits does this relationship bring to the company? Answer: Firstly, it is imperative to reveal that costs are increasing. Virgin raw material is still more convenient than second-hand one. The benefits sit on the environmental sphere: reduction of CO2e, even if limited. Indeed, by performing a Cradle-to-Crave LCA, 95/98% of the equivalent emission comes from the usage phase. Right now, being more sustainable means working on energy efficiency (concerning our market) and in a proper eco-design; shortly, it may happen that changing the energy mix will bring a part of responsibility again in the material and production phase.

Which kind of lever is mandatory to push CE initiatives? Answer: Two actions that work in the same direction are needed: tax relief for the virtuous one and extra taxation for bad behaviour (as seen with mono-usage plastic). The economic sphere is mandatory to sustain the business and R&D costs as a commercial company. Moreover, having recognition for the whole supply chain can push all the players within it to run in the same direction and not have the so-called shifting-burdens problem.

Concluding, manufacturing companies may have some reluctance to disclose in-house scrap. Do this behaviour may limit IS practices? Answer: It is necessary to distinguish between intrinsic scraps that only a boost in machinery's efficiency may reduce and wastes due to bad design or general errors. The latter may be difficult to reveal to competitors or partners. To solve is needed a behaviour change and continuously improve to reduce it, even by opening the company's boundaries and seeking possible allies.

5 | Industrial Symbiosis strategies; barriers and opportunities

The potential for industrial symbiosis is not exhausted. Additionally, there is still a wide range of opportunities for its application. Through the Italian and academic literature analysis, this thesis aims to gather and analyse insights from past research and real contexts to highlight the margin of optimisation that is not being used. Of the various articles published on industrial symbiosis, a significant proportion has focused on the best ways to foster industrial symbiosis and the most effective ways of overcoming the various obstacles, including economic, technological, legal, and social barriers, that are faced in the creation and development of industrial symbiosis. In conclusion, this chapter proposes a comparison between theoretical and "from the field" barriers and opportunities and future-scope actions to foster the Industrial Symbiosis

5.1. Barriers

Although the potential for industrial symbiosis is high, there are several constraints on its implementation. A lack of trust, uncertainty about the benefits, a lack of knowledge of the concept of industrial symbiosis, and a lack of information sharing [18, 29, 32, 33, 45, 51] are the main factors that have been identified as restraining this process. However, some elements are often referred to as drivers for creating and developing industrial symbiosis networks, such as reducing raw material and waste disposal costs and the potential revenue generation [8, 43, 45, 52]. In addition to these aspects, existing policies and Legislation have also been identified as influencing industrial symbiosis practices. Regulatory pressure and landfill tax, which drive companies to find solutions for using resources more efficiently and reducing waste disposal [30], are examples.

Geographical proximity is the decisive factor for initiating synergic collaborations among different companies [7]. It is the main principle in the design of eco-industrial parks and APEAs (Ecologically equipped productive areas) in Italy [17], which can support the idea of industrial symbiosis by collocating different production processes in a way that they can benefit from shared infrastructures and facilitated the exchange of by-products.

Despite the recognised environmental, economic, and social benefits of industrial symbiosis, several barriers hinder its development. The literature review shows that these barriers can be of various types, such as economic, technical, regulatory/legal, organisational, social, and cultural [1, 19, 29, 51]. By analysing selected publications on potential industrial symbiosis, it was possible to identify several of these barriers.

Several studies of potential industrial symbiosis have pointed out the lack of appropriate policies as a barrier to applying this practice. Low taxes on landfill disposal, policies that encourage and regulate industrial symbiosis, a lack of funds to promote this practice, and deficient regulatory frameworks are some of these barriers. In addition, existing Legislation may limit the implementation of synergy relationships, especially if it is too rigid, unclear, or inconsistent.

There are also other barriers to the creation of industrial symbiosis networks. The first is associated with the reluctance of companies to establish synergistic relationships. Lack of knowledge of the industrial symbiosis mechanism and the potential to receive or provide waste discourage the IS application. In addition, a lack of trust, resistance to providing data on processes and generated waste, and uncertainty related to the profitability of the symbiosis network and the associated costs and risks were also identified as barriers to the development of symbiosis relationships.

The fact that companies are implementing measures to reduce waste generation has also been identified as a barrier to developing industrial symbiosis, as there is a concern that the stream of waste involved cannot be guaranteed.

The economic component has been referred to by various authors as being essential in inducing companies to take the initiative to establish an industrial symbiosis relationship. If the economic value of raw materials is very close to that of waste, companies have no incentive to use waste in their production processes. Moreover, the price companies are willing to pay for production leftover may not be economically advantageous for the company producing such waste. In this case, there is no incentive for companies to divert waste from landfills and start a symbiosis relationship. In addition to these factors, the lack of openness and willingness to initiate this kind of collaboration by the top management can be seen as another barrier.

For establishing some symbiosis relationships, such as sharing waste heat, the initial costs associated with infrastructure are very high, which makes companies reluctant to develop such symbioses. A lack of availability of technologies required and the high costs of equipment for the realisation of industrial symbiosis have also been identified as inhibiting the completion of this practice.

A country's social and economic instability can also condition the establishment of synergies since, although the sustainability issue is recognised as necessary, social issues may take precedence. In addition, the matter of survival is imperative in some countries with developing economies, and since the time between setting up projects and achieving results may often be long in these countries, this may constitute a barrier to the implementation of symbiosis.

5.1.1. Industrial Districs vs Industrial Symbiosis

Following the analysis of the barriers, a digression is needed; the critical question is, are the Industrial District a barrier or a driver? Different industries have frequently been highlighted as conducive to establishing industrial symbiosis relationships. Having diversity within the district opens a range of opportunities due to the variety of wastes and the number of companies that produce them, and they have the potential to incorporate them into their processes. If several companies carry out the same economic activity, this can be an added advantage since it ensures a more constant flow of waste. At the same time, if there are no other companies nearby to ensure the incorporation of these wastes into their processes, the viability of industrial symbiosis is compromised, and this is a likelihood with the Italian manufacturing system, a core industry with its auxiliaries in the surrounding area, thus IS proximity with different industries is compromised. Meanwhile, the fact that several initiatives are carried out in the same economic activity may also enhance other synergies, such as infrastructure sharing and the joint provision of services.

Concluding, the presence of a core player can be an essential factor in driving the realisation of industrial symbiosis relationships. Indeed, the head company can function as an anchor attracting a network of companies in terms of the supply of materials and the reuse of waste in the surrounding area.

5.2. Enablers and drivers

Knowledge of the drivers and barriers to implementing industrial symbiosis is essential to develop measures that enhance the application of this practice. This section compiles the various drivers, i.e., factors that promote and facilitate the development of industrial symbiosis, and barriers, i.e., the factors that hinder the implementation of this practice. Selected strategies for overcoming the various obstacles are also highlighted, as these can create conditions for multiple cases of potential industrial symbiosis to materialise.

An analysis of the articles concludes that several factors play a crucial role in realising industrial symbiosis relationships. In most cases, it is not one factor but a set of characteristics that create favourable conditions for developing symbiosis. A country's economic, environmental, political, and social context can be decisive in how sustainability issues are addressed and, consequently, how they can favour or condition the development of industrial symbiosis. Knowing the environmental, economic, and social benefits that this practice provides is vital in promoting the creation of synergy networks; however, these are not always the main drivers of this practice, and many other drivers have been identified in studies of potential industrial symbiosis as being conducive for companies to participate in symbiosis networks.

Existing Legislation, plans and policies in each country are also repeatedly referred to as drivers of industrial symbiosis, as seen in chapter 2. Companies are encouraged to set up synergy networks by imposing limits on emission or waste disposal through regulations and taxation, facilitating the use of waste, and allocating funds.

Although not an indispensable requirement for establishing the synergy network, geographical proximity between the potential participants in industrial symbiosis is often referred to as a facilitator [49]. Establishing symbiosis networks with nearby companies can increase trust in the relationship. In addition, because waste is mostly of low economic value, transportation and environmental costs may no longer compensate for the symbiosis connection over long distances. The existence of industrial symbiosis networks that have already been established in each place can be a driving force for creating new synergy linkages and extending the network to new companies since the internal structures and trust relationships that facilitate this development are already established [35]. There is evidence that these networks can benefit the parties involved, not only in terms of reducing waste treatment and landfill costs but also in terms of the savings made in acquiring raw materials and profits from the sales of waste.

5.3. Theoretical and "from the field" comparison

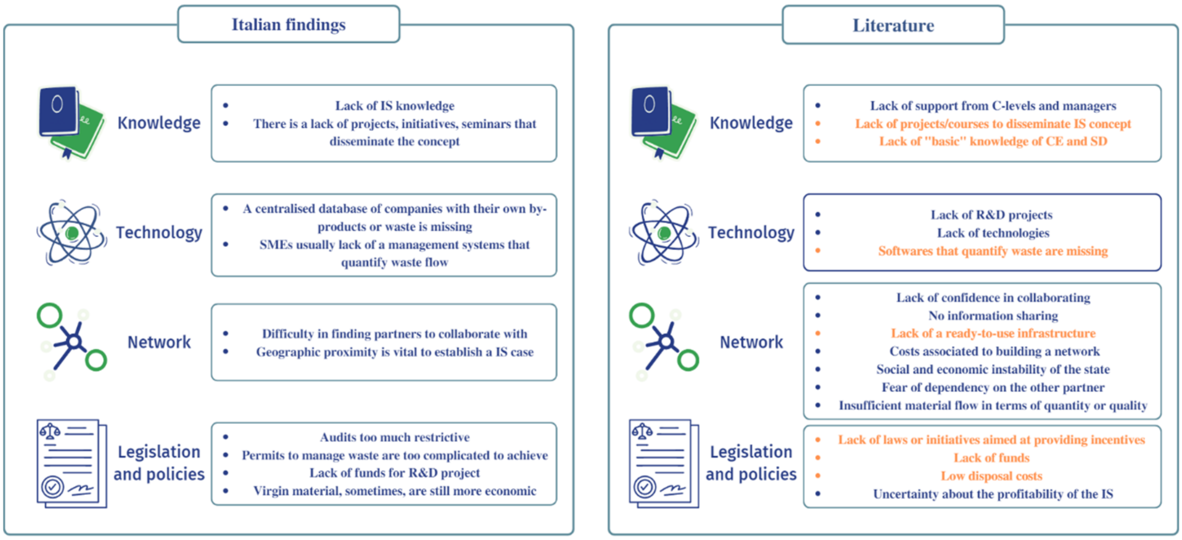


Figure 5.1: Barriers comparison analysis

The image, 5.1, proposed a graphical comparison of the barrier collected during the interviews and the one from the academic literature review. Clusters of the barriers are knowledge, technology, network, Legislation and policy. The economic one is intentionally avoided because it leverages others and thus is the most important and influential. The orange-write actions in the literature field are the ones that are confirmed by the Italian working field, while the blue ones are not verified, as will be explained in the conclusion of this paragraph. In the following section, a comparison analysis is steered.

- Economically. From the entrepreneur's and manager's point of view, the paper review also shows that even if the direction is set, which is "sustainability", however, if the model is not financially profitable, the other cluster needs to support and play a role in making the business model gainful.
- Knowledge. Most actions are confirmed; the lack of familiarity regarding this "new" economic field. Limited awareness is influenced by the low presence of seminars and workshops that diffuse IS. The theoretical action of low support from the C-level cannot find any approval by the working field because all the respondents and analysed cases are pursued thanks, primarily, to the entrepreneur's and managers' commitment.
- Technology. In this cluster, academics argue that a lack of technology and R&D projects can be linked to low economic support, which is confirmed, but, according

to the respondents, those actions should go in another cluster, the Legislation and policy one. More critical is the confirmation of a lack of technological support (software, databases); something that is not measured cannot be improved. Thus, the first step is to quantify waste, and then IS can become a vital model.

- Network. This cluster needs deep reasoning because the two actors, interviews from confirmed cases of IS and academics, have different points of view. Most papers show that creating a network can be the most challenging barrier to exceed due to the need for geographic proximity, collaboration, commitment, trust and information sharing. Thus, those actions are confirmed by potential cases of IS and could be approved by other firms not running a IS case. At the same time, respondents argued that it could be challenging to find a partner, but only by only an economic point of view because the partner needs to be close, and the cost of a leftover does not have to be higher than a virgin one. Indeed, trust, commitment, and information sharing can be built. Both confirmed a lack of an already established network, but as seen in the facilitator paragraph 4.1, the SUN can help firms create the necessary linkage.
- Legislation and policies. Here is where policymakers need to start making a difference. Legislation is nested under the monetary influence. Indeed subsidies and tax relief or, by tackling the other coin face, setting new taxes on virgin material usage can support the diffusion of IS and other CE business models.

In conclusion, a possible bias could be present in this analysis because the scope of this Thesis, regarding the Italian findings, was to map and interview real case managers and entrepreneurs. Thus, some disagreements are presented, as shown previously, but some comfirm cannot be found (e.g., lack of management support). A possible follow-up analysis could be interviewing potential cases; still under development or companies not running IS projects to see if other matches can be found and complete the investigation.

5.4. Conclusions

While a given entity decides to establish a symbiosis relationship, the role of policies is critical in encouraging this practice. Regulations and procedures were often considered necessary for promoting or limiting the establishment of industrial symbiosis relationships. Thus, for these to not function as barriers, it is required to provide Legislation and policies that are clear, consistent, and less bureaucratic and can facilitate the process of waste use.

Economic incentives have also been highlighted as necessary in realising industrial symbiosis. Programmes can be coupled with the provision of funds to promote industrial symbiosis and offer companies monetary support in constructing infrastructures or acquiring the equipment necessary for realising these relationships. Moreover, economic support such as subsidies or R&D tax relief needs to be constant and not a high quantity of Una Tantum to discourage moral hazard or lousy behaviour.

However, even if some policies and programs facilitate and encourage companies to establish symbiotic relationships, the companies are often reluctant to make such connections. Thus, it is necessary to disseminate information to companies to drive the implementation of industrial symbiosis. This can be realised through workshops, working group discussions, and other actions that provide the necessary information to companies on industrial symbiosis and its potential benefits. A knowledge of this practice can create the willingness to cooperate, which is fundamental for realising symbiosis networks.

The role of facilitators has been highlighted as a way to overcome various barriers, including a lack of confidence, a reluctance of companies to share their data and a fear of relying on other companies. These entities can train employees on industrial symbiosis, assist in creating trust and cooperation relationships, and help identify new symbiosis relationships. Some barriers can be overcome using digital platforms and programs. These tools can enable social interaction between companies and facilitate searching for companies that can provide or receive waste.

To overcome the barriers associated with a lack of available technology, governments need increased investment in research and development into technological innovations and greater involvement with research teams from universities or business associations.

To conclude, as previously suggested, another voice should be heard to complement the proposed investigation: companies that do not know or have encountered obstacles in realising IS cases. Thanks to that, the theoretical barriers that are not confirmed can be further analysed. Furthermore, A DEMATEL study can be performed to numerically contextualise the relationship between barriers and levers to overcome them in case of substantial company survey participation.

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A | Appendix A

Industrial Symbiosis and Circular Economy questions:

- Once defined the IS concept the firm is aware of being a case of it. Was it something "natural", a common path to pursue, or something sought?
- For how many years was the specific IS project presented in the company?
- What kind of benefits has been found (e.g., reduction of CO_2e, economic benefit, waste reduction)
- What kind of difficulties has been found (e.g., too many laws and restriction, lack of network, too high cost)
- Do the firm use KPIs or standards to measure its impact (e.g., GRI, SDG goals, Circulitics)
- If you could propose a lever or a policy that can foster the IS, which would you suggest?

Sustainable Development questions:

- Your company mission commits to a social or environmental goal
- There is a sustainable strategy (e.g., reduce the CO_2e of x%, employees gender equality)
- Do you disclose your social and ecological plan (e.g., publishing the sustainability report)
- Which kind of SDGs are you pursuing right now
- Among the commitment, do you have any legal bind in pursuing a sustainable development (e.g., being a B-Corp, being a Social Venture)

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List of Symbols

Acronym	Description
IS	Industrial Symbiosis
CE	Circular Economy
EU	European Union
ENEA	"Ente per le nuove tecnologie, l'energia e l'ambiente"
Sun	Symbiosis User Network
ID	Industrial Distric
IE	Industrial Ecology
SD	Sustainable Development
WtE	Waste to Energy
SME	Small Medium Enterprise
SDG	Sustainable Development Goals
LCA	Life Cycle Assessment

Acknowledgements and Personal Reflection

A.1. Personal reflection

To conclude this Thesis, which also concludes my study path, I would like to mention two pieces of reasoning taken from lectures at Poli.

The first one comes from professor Lapko. During a lecture, while digressing into the limit to growth, the scarcity of resources and the fixed-stock paradigm, the professor asked a crucial question: "Should we go full speed relying on innovation?". Explaining it better, she put on a continuum line two different strategies or ethical choices from two scholars:

- Malthus "If the world's population grows faster than the planet's ability to produce food and other necessities, at a certain point, it will lead to a sudden population collapse".
- Solow "If it is easy to substitute other factors for natural resources, then there is, in principle, no problem. The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe."

So, should we preserve the planet and stop production? Or go full speed relying on innovation? Before answering the question, I would also like to add another reasoning held by professor Chiaroni. In his lecture, the crucial question was: Is Circular Economy the only solution to the scarcity of natural resources? Or can other strategies be pursued? His reasoning concludes that further actions can be taken, such as keep improve efficiency or applying Austerity. Both approaches have, as a result, less resource usage, but the former work on the input side (fewer resources given by less consumption), while the latter is on the demand side (fewer resources provided by less output imposed).

Trying to answer those complex questions alone is quite complicated; a very compound and demanding future is ahead, but I fully believe that the direction to follow is only one: embrace Sustainable Development in all its forms and with concrete actions. The world community shows how in a difficult period, such as the Corona Virus Phandemia, can cooperate in the same direction for human well-being. Relying on Austerity or stopping growth are only desperate solutions and will reduce people's welfare.

Concluding I genuinely think that soft actions work in no direction; they postpone a problem, remanding decisions to future generations. By citing William Ruto, President of Kenya: "In the face of impending catastrophe, whose warning signs are already unbearably disastrous, weak action is unwise. No action is dangerous."

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